Geologic Site of the Month

February, 2011

Setting the Stage for a Course Change at Popham Beach, Phippsburg

43 44‘ 2.36“ N, 69 47‘ 39.29“ W

Text by
Stephen M. Dickson

Introduction

Popham Beach in Phippsburg, Maine has changed dramatically in the last two decades. As regular visitors to the beach have observed, the beach and dunes are different from one year to the next. In 1990 the beach was backed by an enormous dune field and visitors walked long paths to reach the shoreline. Even in 2005 there were large dunes in the area of Center Beach (Figure 1).

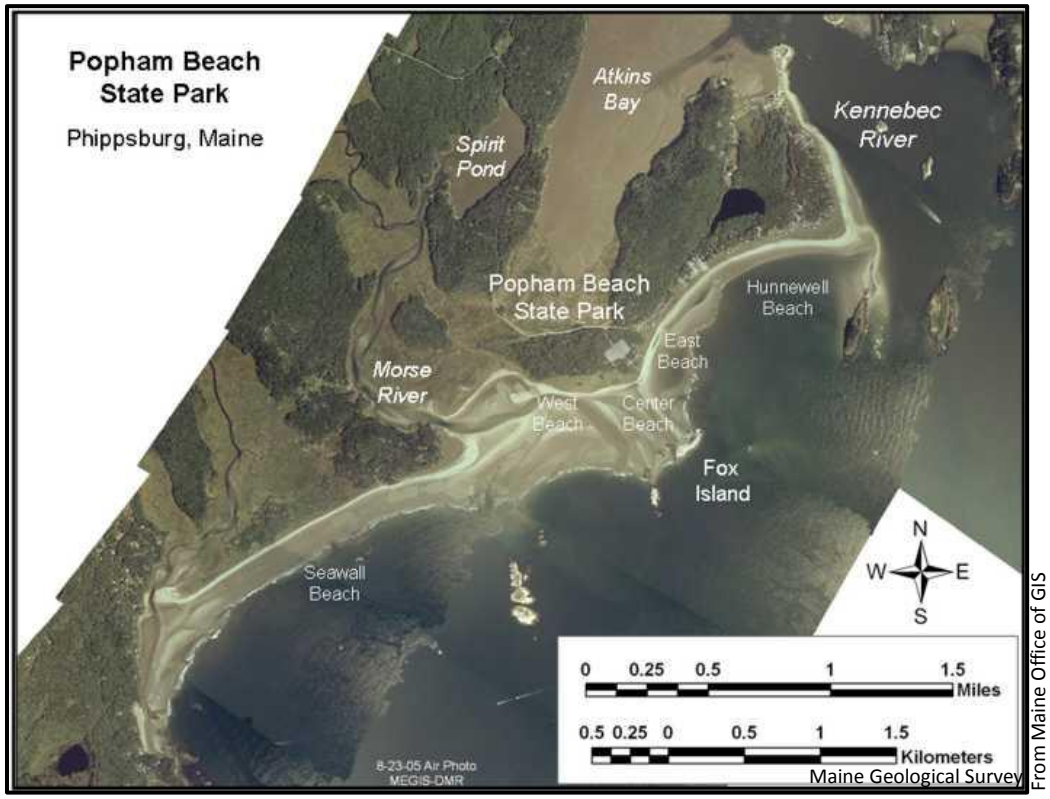

Figure 1. Location map of Popham Beach State Park, adjacent beaches, and water bodies. Note the background air photo was taken in 2005 and shows a large vegetated dune field near Center Beach. The sand bar from the park out to Fox Islands is called a tombolo by geologists.

Introduction

By 2010 the shoreline was hundreds of feet closer to the parking lot and encroaching on a new bath house. In addition, the last few years have seen hundreds of large pitch pine trees topple onto the beach as a result of erosion driven by the Morse River cutting a long and sinuous path in an easterly direction into the state park before turning south to reach the ocean. In the last week of February and first week of March 2010, the Morse River dramatically changed its direction and cut a more direct course to the sea. As a result, the worst erosion cycle Popham Beach State Park has ever experienced has come to an end and the next several years should see beach and dune building as a period of accretion begins. This website chronicles the dramatic changes at Popham Beach State Park over the last few years.

April 2009 - An Overwash Channel Forms

On April 7, 2009 Bates College geology professor Mike Retelle and his students were at Seawall Beach to measure the sand bar that is seaward (south) of the Morse River's tidal inlet. This sand bar, also called a beach spit by geologists, had grown and extended eastward across the mouth of the Morse River for several years. Their field survey was just after a storm on April 6 that came during a period of high tides and coastal flooding to a level of over 11 feet above Mean Lower Low Water (MLLW) for two sequential high tides recorded at the Portland tide gauge (Dickson, 2007; Dickson, 2009 - Figure 12). During their survey, the Bates College team found evidence of storm washover and downward erosion of the sand bar (Dickson, 2009 - Figure 13, Figure 14, Figure 15). This was the first sign that an avulsion, or course change, might occur in the Morse River.

That particular storm had a combined tide and storm surge 2 feet above mean high water. That water level is not exceptional among annual winter storms on the Maine coast and it is possible that similar episodes of erosion occurred in prior winter storms in 2009. To put this storm in perspective, storm surges of 3 to 4 feet are possible adding to the normal elevation of the tides (Dickson, 2007). The 2007 Patriots' Day Storm had a surge of up to 2.5 feet over 7 high tides during a period of astronomically high tides (Slovinsky, 2007; Slovinsky and Dickson, 2009) and resulted in sand deposition into Popham Beach's dunes (Dickson, 2008 - Figure 7). The early April 2009 storm had rather common storm wave characteristics with wave heights of 10 feet with a dominant period of 8 seconds at the Casco Bay buoy (NDBC, 2011). It was concluded that it may take a larger storm event and continued seaward erosion into the spit by the Morse River channel to result in a lasting breach (Dickson, 2009).

November 2009 - The Forest Falls

By the fall of 2009, the Morse River had cut deeply into Popham Beach State Park causing erosion that removed primary frontal dunes and carved into back dunes to fell mature trees from a pitch pine (*Pinus rigida*) maritime forest (Dickson, 2010 - Figure 12, Figure 16). The climax forest here is the largest, most northern such stand of trees in the Gulf of Maine (Nelson and Fink, 1980). Based on the presence of a mapped forest on an 1879 nautical chart (*Survey of the Coast, From Seguin I. to Cape Elizabeth, Maine, scale 1:80,000, Maine State Archives*), the forest and possibly these trees may be as much as 100 years old. This 2009 shoreline may be the farthest inland the Morse River has meandered since the mid 1800s or earlier.

An aerial reconnaissance flight on November 10, 2009 by John Picher of the Department of Conservation showed a thin neck in the Seawall Beach spit at the outside (erosional) bend of the Morse River channel (Dickson, 2010 - Figure 17). The overwash channel was visually estimated to be 10 to 11 feet above MLLW and perhaps 200 feet wide (Dickson, 2010 - Figure 18). The presence of the narrow spit neck and the overwash channel led the Maine Geological Survey to predict a river course change, or avulsion, at that location sometime in the near future.

November 2009 - The Forest Falls

Near the western bath house at Popham Beach State Park, the river bank along West Beach eroded landward at a rate of 10 to 15 feet a week in November 2009 (Figure 2).

Figure 2. A November 11, 2009 view of the edge of the Popham dunes and forest along West Beach. Pitch pine trees were actively being undercut by Morse River erosion and wave action and falling on West Beach.

November 2009 - The Forest Falls

Erosion was most rapid during storms but the ebb and flood currents in the Morse River most likely led to additional sand being swept away between storms along the outer bend in the river (Dickson, 2010 - Figure 15). The Department of Conservation considered and implemented a plan to slow erosion that included moving fallen trees downstream to the vicinity of the bath house. The goal was to emulate the natural process observed along the river bank nearby where fallen trees were slowing the flow, resulting in a wider beach, and reducing bank erosion and forest loss (Dickson, 2010).

December 2009 - The Beach Moves in on the Bath House

Storms continued to erode Popham Beach State Park in December. A prolonged series of strong fall and winter storms allowed the Morse River to become repeatedly elevated and sweep away large amounts of sand in a matter of hours from the edge of the forest at the state park (Figure 3 and Figure 4).

Figure 3. A December 3, 2009 southeaster sent large irregular surf directly to the edge of the dunes and forest at high tide. Fortunately some of the surf broke offshore on sand bars, reducing the energy in the waves reaching shore.

December 2009 - The Beach Moves in on the Bath House

A storm on December 12 elevated the tide with a 1.5-foot storm surge and resulted in minor coastal flooding over the 12-foot level. Offshore waves in this storm were 12 feet high. Surf broke on sand shoals offshore of Popham Beach State Park and moved ashore as smaller waves that still managed to erode the forested dunes and cause flooding in low areas (Dickson, 2010-Figures 9-11).

Figure 4. A December 3, 2009 southeaster. As waves scoured the toe of the sand bluff, alongshore currents driven by the Morse River removed sand from the beach.

December 2009 - The Beach Moves in on the Bath House

There was a general, but undocumented, consensus from eye witnesses that erosion was reduced by the trees temporarily bundled with ropes in front of the bath house - just 75 feet from the building (Figure 5; Dickson, 2010 - Figure 14). The vertical cut down to the beach is 5-10 feet below the grade the bath house sits on.

Figure 5. Each big storm moved the ocean 15 feet closer to the bath house. Ropes tied fallen trees together and then were secured to living trees to hold them in place.

February 2010 - Setup for a Breach

With only a month left in the winter storm season, conditions were set up for a major storm in the Gulf of Maine the last week of February. Predicted tides would be some of the highest in a year. A storm centered over Connecticut developed a low barometric pressure of 972 millibars that created strong onshore winds along the Maine coast. On February 25, storm tides ran higher than normal as a result of the wind-driven surge. From February 25 to 26 waves at the Portland buoy were 15 to 28 feet (Figure 6). These extreme waves were only 2 to 3 feet below the historic October 1991 Perfect Storm and the April 2007 Patriots' Day Storm.

Figure 6. Waves at the Casco Bay buoy (No. 44007) off Portland. Waves, and thus surf at Popham Beach remained elevated into March. Significant wave height is the average of the one-third highest waves recorded over 20 minutes.

February 2010 - Setup for a Breach

On February 27, after the peak waves of the storm passed, the Maine Geological Survey determined that only a shallow and wide overwash channel had formed on the Seawall Beach spit (Figure 7). It was clear that the storm did not open a permanent new channel that the Morse River could pass through at all stages of the tidal cycle.

Photos by S.M. Dickson

Figure 7. Two views on February 27, 2010 from the Seawall Beach spit looking north toward West Beach at Popham Beach. (Right) The washover channel (right) still holds water but is only a foot deep and well above the depth of the Morse River channel in the background. (Left) Emery Beach Profiling rods and tape measure in the foreground are at the eastern terminus of an elevation survey started at the dune in the background.

February 2010 - Setup for a Breach

An Emery Method beach profile survey on February 27 across the channel and parallel to the beach showed a broad lowering of the spit relative to surrounding areas (Figure 8 and Figure 9).

Figure 8. The Emery Beach Profile spanned the shallow channel that would become the new Morse River channel in about a week. Elevations are recorded in centimeters from the higher of two poles and a line with the horizon.

February 2010 - Setup for a Breach

The cut in the spit was about 300 feet wide at the spring high tide level and about 200 feet across at the mean high tide level. So elevated storm tides were able let the Morse River flood and ebb on a more direct path to the sea.

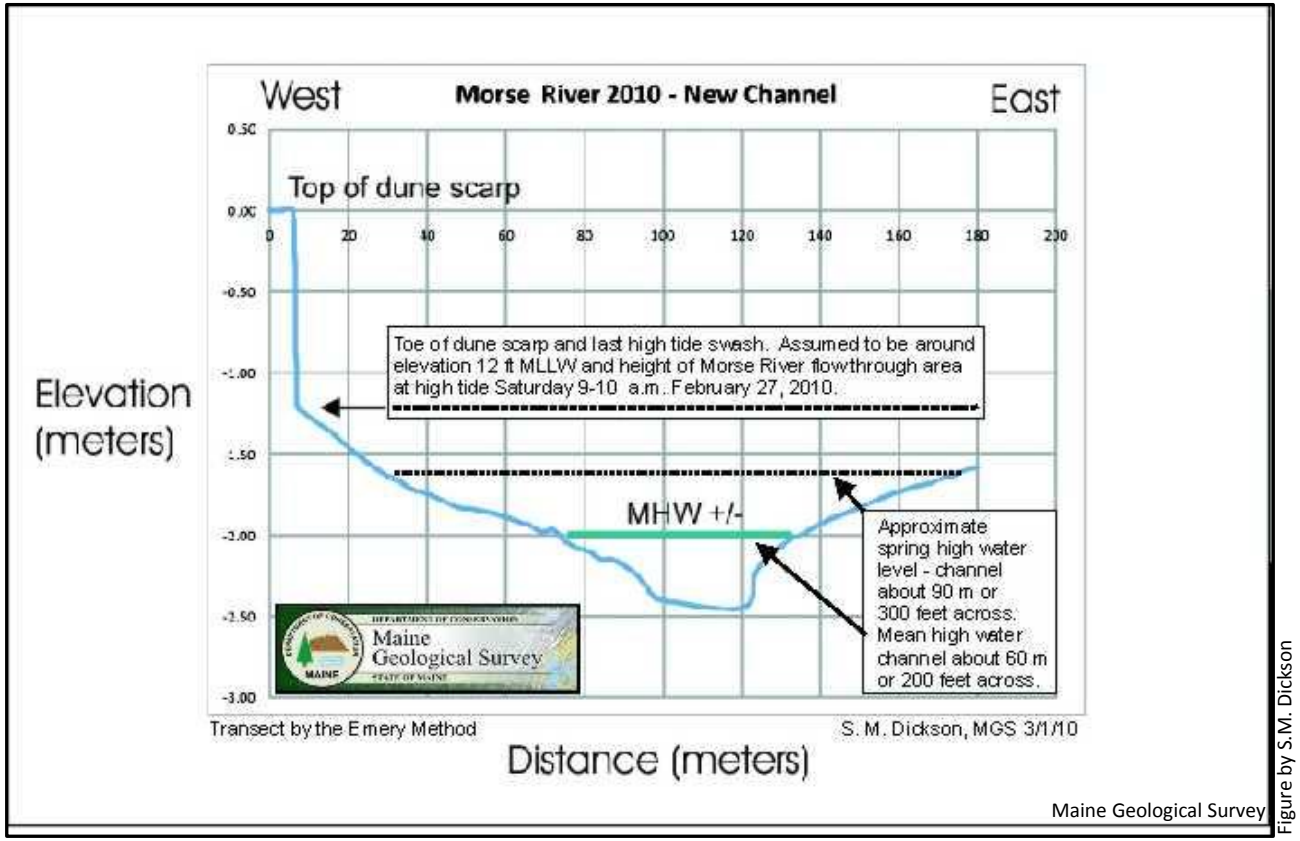

Figure 9. The transect across the overwash channel on the Seawall Beach spit. The transect runs parallel to the beach and is about 180 meters (590 feet) long from west to east across the most shallow portion of the channel. The vertical exaggeration (about 40 times V:H) helps to show the shape of the channel cross-section.

February 2010 - Setup for a Breach

After the water level fell below a normal high tide elevation, the river still was confined to its old path along Popham Beach State Park. At this point, it remained uncertain if additional surf would (a) deposit more sand in the overwash channel and seal it up or if (b) overtopping by waves and tides would keep this section of the beach spit low and allow for more downward erosion. These competing coastal processes were quite dependent on the nature of waves coming ashore, the strength of tidal currents, and water levels from both tides and storms.

A unique set of meteorological and oceanographic conditions followed the February 26 storm. There were 7 days of high "spring" tides that allowed the river to ebb and flood across the sand spit. Just before midnight on February 25, 2010, the Portland Tide Gauge recorded a 4.37 foot surge. Since 1912, the highest surge recorded in Portland (at high tide) was 4.6 feet on March 3, 1947. For a period of 9 days, from February 24 through March 4, there was also coastal flooding from a persistent storm surge of 1 to 2 feet. The Blizzard of February 7, 1978 had a 3.5 foot surge but it occurred during an extreme high tide and holds the highest record for water levels - 2 feet above this storm.

February 2010 - Setup for a Breach

These conditions resulted in 15 extra high tides (Figure 10). With each exceptionally high tide, more water was able to flow up the Morse River, enter the back-barrier salt marshes, and elevate Spirit Pond (Figure 1).

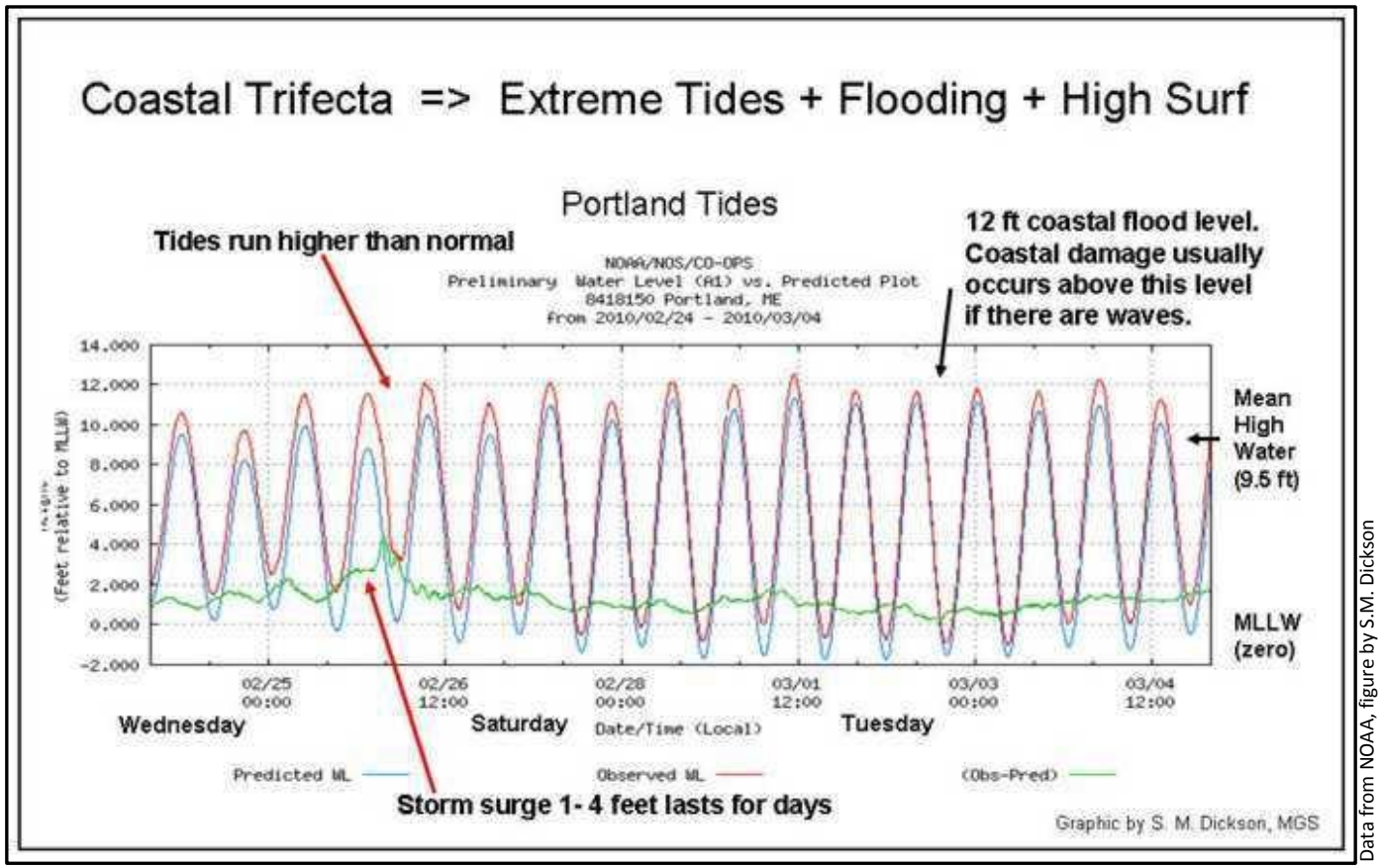

Figure 10. This graph shows the difference from the observed tide (red) and predicted tide (blue). The difference is the storm surge amount (green). Tides exceeded the 12-foot level 5 times in 4 days at the Portland Harbor tide gauge.

February 2010 - Setup for a Breach

This increased volume of water needed to exit over a fixed number of hours on a falling tide, so tidal currents were stronger than normal. Faster flood and ebb currents are capable of moving more sand off the top of the spit, and deposit it either into the deeper Morse River or offshore into the surf zone. During this period of stronger tidal flow, moderate waves, in the 5-foot range, continued to create surf, wave action, and turbulent flow across the spit around the time of high tide.

With each successive tidal cycle, we expect that more sand was removed from the spit and lowered its peak elevation in the overwash channel. Lowering would have led to even longer tidal flow in and out of the Morse River and thus more duration of erosion on the spit. Since a straight path to and from the sea is hydraulically more efficient, the Morse River would have preferentially flowed across the spit when it had the opportunity during this week.

March 2010 - Final Breach

By March 6, 2010 the 9 days of stormy weather were over. A reconnaissance survey by Laura Sewall, the Director of the Bates-Morse Mountain Conservation Area, documented active Morse River flow through the new channel.

Figure 11. A photo from March 6, 2010 of the new Morse River channel looking north toward West Beach. The rapid downward erosion of the channel results in a steep vertical cut into the sand spit (right) where large blocks of sand fall into the flowing channel. Bank erosion even exhumed a buried yellow lobster trap.

March 2010 - Final Breach

This was the same location that was progressively lowered by storms in the previous year and more deeply incised in late February and early March (Figure 11 and Figure 12).

Figure 12. A photo from March 6, 2010 of the new Morse River with waves helping to suspend sand and scour the channel deeper. In the background is surf breaking on Seawall Beach.

March 2010 - Final Breach

Once this new connection to the sea had been started, tidal ebbing and flooding of the Morse River rapidly led to additional channel deepening and widening.

Figure 13. The Seawall Beach spit (sand bar) was cut by the February 25-26 storm. Large tides and surf continued to lower the bar for a week - through March 5 and 6 - when deep erosion formed a new tidal channel with a straighter and more direct course to the sea. The stranded tree on the far bank of the channel is the same one in Figure 7.

March 2010 - Final Breach

Sand was deposited into the old course of the Morse River resulting in shoaling that made the former channel hydraulically less efficient and helped to confine more flow in the new channel (Figure 13-15).

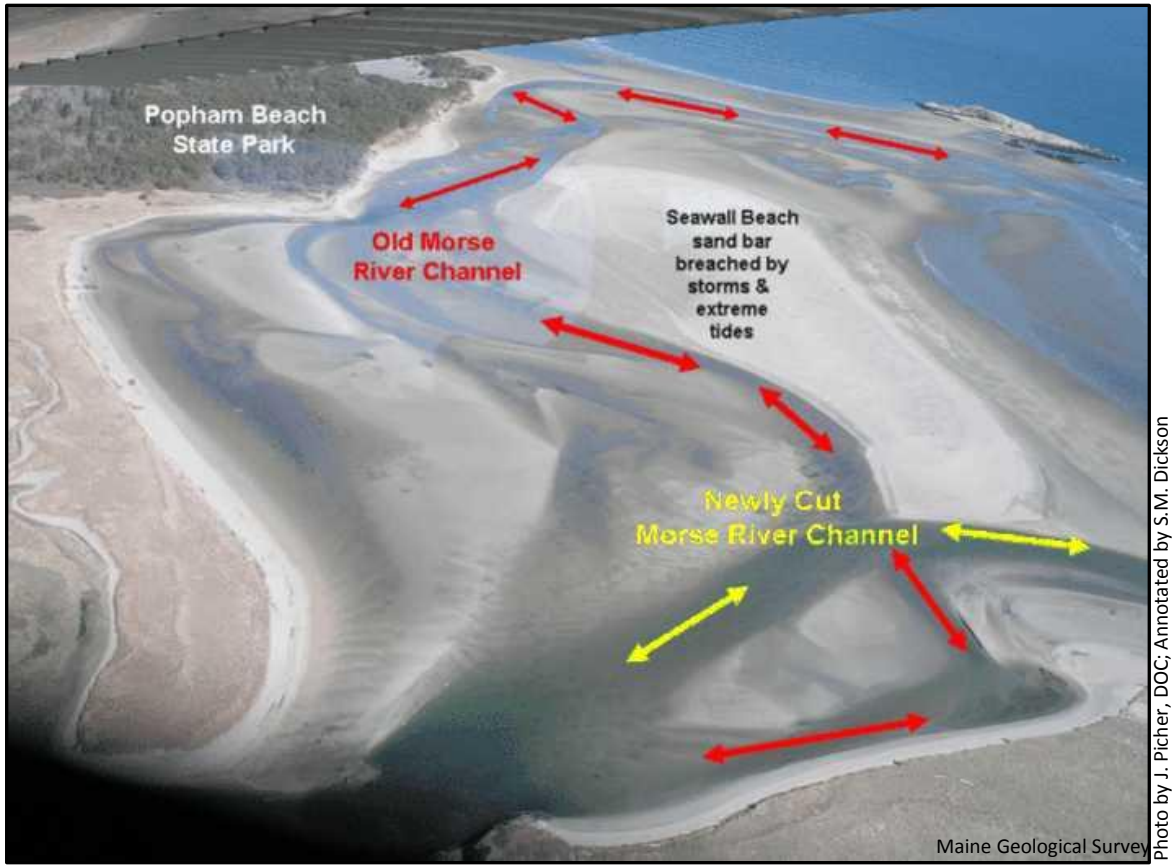

Figure 14. The Seawall Beach spit became a sand island as a result of the new Morse River channel. The shorter path to the sea (yellow arrows) is more efficient and becomes the dominant channel as the old channel fills in with sand.

March 2010 - Final Breach

Figure 15. An aerial view from over Fox Island and its tombolo (sand bar in foreground leading to the state park dunes). The meandering course of the Old Morse River is marked by red triangles. The new channel is shown by green triangles. The newly formed sand island is in the center with Seawall Beach and Casco Bay in the background.

August 2010 - Closing the Old Morse River Channel

The breach resulted in the separation of the spit from Seawall Beach. This process led to the formation of a low-relief sand island that was surveyed by the Maine Geological Survey on March 27, 2010 (Figure 16). The shoreline positions were recorded with a hand-held Garmin 12Map GPS.

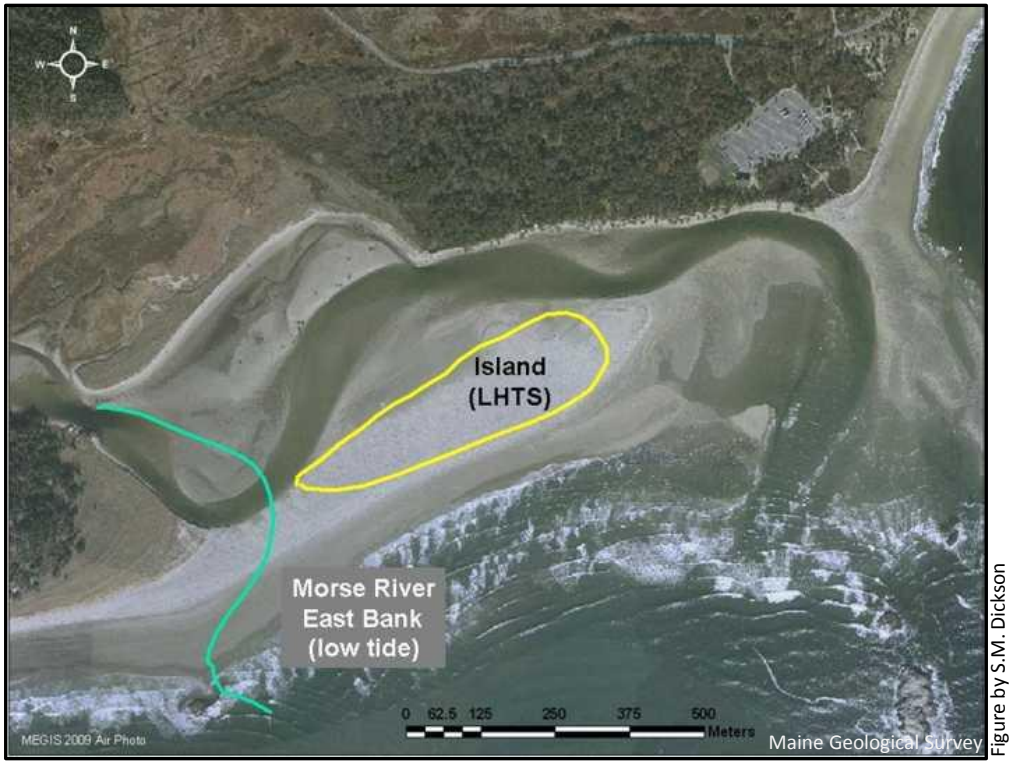

Figure by S.M. Dickson

Figure 16. Comparison of the high water mark (last high tide swash line - LHTS) around the sand island (yellow) with the east bank of the Morse River (teal line) at low tide on March 27, 2010. A 2009 air photo shows the former path of the Morse River and fallen trees along West Beach at the state park (photo courtesy of the Maine Office of GIS).

August 2010 - Closing the Old Morse River Channel

By August 20, 2010 the former channel of the Morse River was blocked by sand swept northward off the western end of the island to form a small spit platform upstream (Figure 17).

Figure 17. Aerial view of Popham Beach and the sand island on August 20, 2010. In the foreground, sand has been transported off the island in a shoreward (left) direction and resulted in the infilling of the former Morse River channel.

November 2010 - The Island Moves Landward

Through the summer and fall of 2010, sand continued to be reworked by waves and tides. From March through November 2010, the sand island migrated 500 to 700 feet east-northeast toward the state park while retaining its overall subaerial exposure. Concurrently, the Morse River's new channel began to migrate easterly (Figure 18). This pattern of channel movement is consistent with what it has done in the past (Goldschmidt and FitzGerald, 1991).

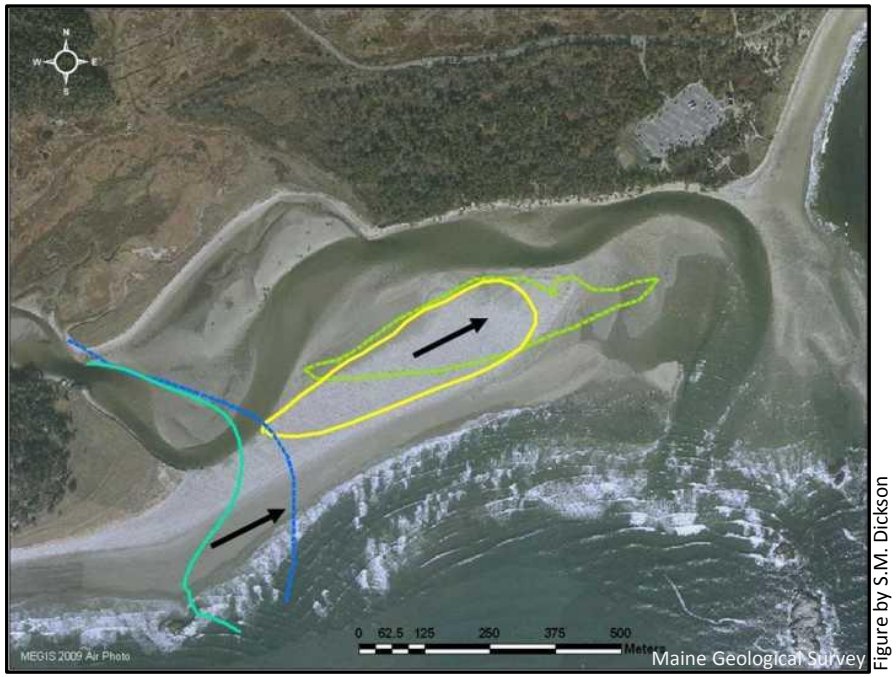

Figure 18. In 2010 the sand island migrated toward Popham Beach. March 27 (yellow) and October 29 (green) high water lines show an east northeast movement. The Morse River's eastern bank at low tide also migrated easterly from March 27 (teal) to October 29 (blue). Shoreline positions were recorded with a hand-held Garmine 12Map GPS.

November 2010 - The Island Moves Landward

The dramatic change in shoreline positions is best seen by overlaying the 2010 island perimeter in relation to the dunes in a 2003 air photo (Figure 19). Remarkably, the landward edge (approximately the high tide line) of the island now overlaps the area where the seaward edge of the park dunes was back in 2003. Shoreline positions were recorded with a hand-held Garmin 12Map GPS.

Figure by S.M. Dickson, Photo courtesy of MEGIS/Delorme

Figure 19. The October 29, 2010 island shoreline (LHTS, short dashed green line) is superimposed on a 2003 air photo. The fall 2010 island position slightly overlaps the 2003 dune field. The October dune/forest edge is shown in the upper dashed green line and the east bank of the Morse River is in the blue dashed line.

Shoreline Change at Popham Beach State Park

Historical shoreline change has been previously documented (FitzGerald and others, 2000; Nelson, 1979) as has the meandering of the Morse River (Goldschmidt and others, 1991). Nelson and Fink (1980, p. 110) described the shoreline at Popham Beach State Park as "...among the most unstable in Maine." FitzGerald and others (2000) estimated that the state park lost an average of 74,000 m3/yr from 1942-1953 and gained 15,000 m3/yr from 1953 to 1979. The last time the shoreline was close to the pitch pine forest was in 1953 (Dickson, 2008 - Figure 12).

Recent shoreline change along the dune edge shows the pattern of erosion at Popham Beach State Park that led to unprecedented dune and forest loss since 2005. It is clear that the Morse River began to encroach on the state park dune field before the 2007 Patriots' Day Storm and that a considerable area of open dunes were lost from 2005 to 2007.

Shoreline Change at Popham Beach State Park

The pattern of erosional loss is consistent with easterly migration of the outer bend, or cut bank, of the Morse River (Dickson 2010 - Figure 7). From 2007 through January 2011 the erosion trend at the state park continued with a progressively easterly loss of dunes, losing as much as 500 feet of the open dune field at Center Beach (Figure 20). From 2009 to 2011 the area removed by erosion lessened slightly but the entire shoreline from West Beach to East Beach continued to erode.

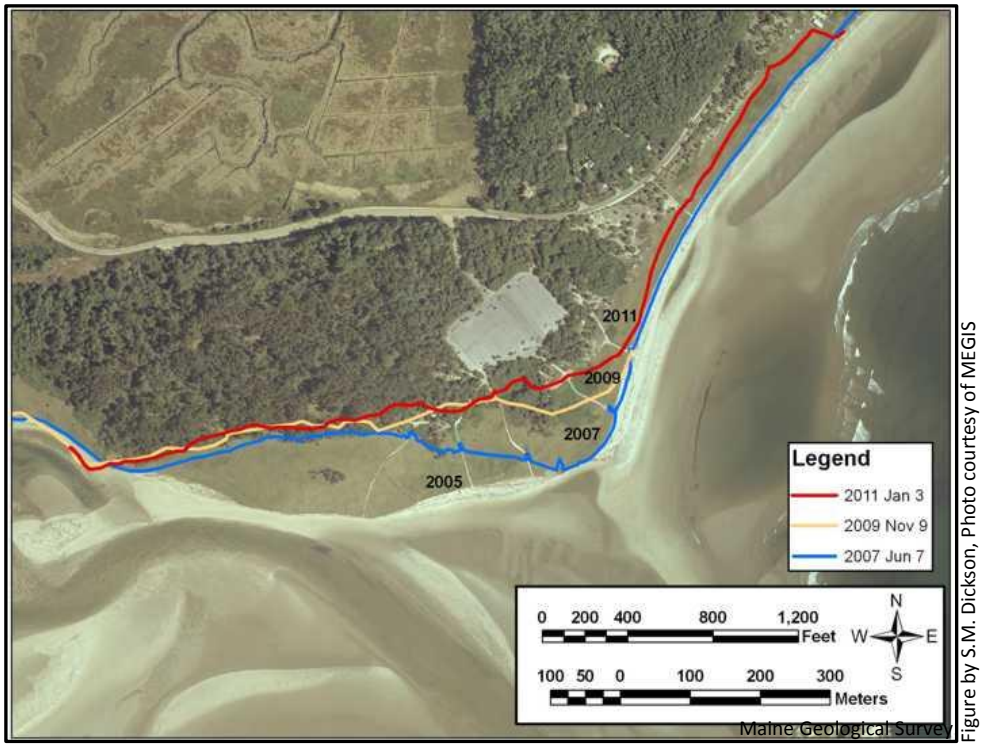

Figure by S.M. Dickson, Photo courtesy of MEGIS

Figure 20. Shoreline change map at Popham Beach from 2005 shown in the photo to 2011. Real-time kinetic GPS was used for the 2007 and 2009 shorelines by MGS summer interns J. Howard and L. Wurst. A Garmin 12Map GPS was used to measure the January 2010 shoreline.

Shoreline Change at Popham Beach State Park

From 2007 to 2011, erosion took place on East Beach and severely compromised the height of the frontal dune, particularly on the eastern end. The lower dune ridge is now more susceptible to wave overtopping and additional sand deposition on the back slope of the frontal dune ridge (Figure 21).

Figure 21. January 3, 2010 photo of low frontal dunes at the eastern end of East Beach. Storm waves and flooding have deposited sand and driftwood into the dunes. Erosion has removed some of the higher frontal dune ridge at this location so flooding is more able to reach farther inland.

Shoreline Change at Popham Beach State Park

Based on shoreline positions from 1980 to present, the area of vegetated dunes at the state park is now about the lowest on record (Figure 22). The largest dune area was present in 1991 and represents the most southerly extent of dunes at Center Beach in the last 30 years. From 1991 to 2003 the Morse River removed dunes on the west side of the dune field but the center remained stable. From 2003 to 2011 erosion by the Morse River progressed eastward (Figure 20).

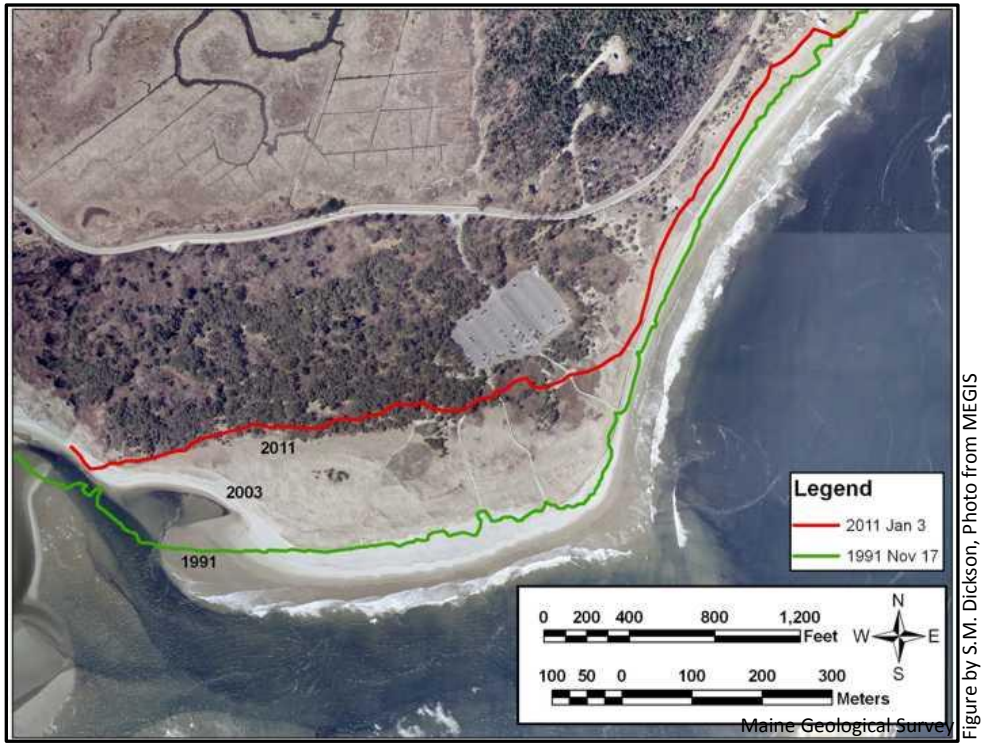

Figure by S.M. Dickson, Photo from MEGIS

Figure 22. Map showing shoreline change at Popham Beach from 1991 to 2011, with the maximum and minimum edge of the dunes. The 1991 shoreline from an historical vertical photograph about 3 weeks after the Perfect Storm (October 31, 1991), shows an irregular dune edge. The 2011 shoreline was recorded using a hand-held Garmin 12Map GPS.

Discussion

The last time the Morse River breached the sand bar was November 23, 1986 (Goldschmidt and others, 1991). Goldschmidt and others estimated that about 100,000 m3 of sand migrated onto Popham Beach State Park as a result of that course change in the river. Based on partial submergence of the sand bar in an air photograph taken about 18 months before the breach (May 9, 1985; Goldschmidt and others, Figure 3) the sand bar was significantly lower than it was in 2009 when tides could not routinely overtop it. The 1986 breach was followed by breaching of the Fox Island tombolo whereas in 2008, the tombolo was breached prior to channel avulsion (Dickson, 2008). It remains to be seen if the onshore migration of the island leads to another tombolo breach in the near future.

In the next few years the sand island should migrate ashore and weld onto Popham Beach State Park. As sand moves ashore, the intertidal beach will become much wider and the height of the tombolo to the Fox Islands should increase providing additional recreation space and protection for the remaining dunes at Center Beach. Based on past trends, the next several years should see additional dune building from wave and wind action. Once the upper dry beach, or berm, reaches an elevation above the spring high tides, American beach grass should colonize the area. Vegetation, if kept from excessive foot traffic, will trap additional sand and lead to further dune building. Given the large size of the island, the area of dunes built over the next decade may reach an equivalent area to those removed in the last decade - possibly completing a natural cycle that began about 20 years ago.

Conclusion

Popham Beach at the mouth of the Kennebec River is one of Maine's premier public beaches. The beach and dunes have been highly dynamic based on historical evidence. The geology of the system is complex and affected by bedrock islands that affect wave shoaling and by the ebb and flood of currents in the Kennebec and Morse Rivers. Geological evidence of impending spit breaching by the Morse River was observed for about a year. It took a trifecta of large storm waves, coastal flooding, and extreme tides for an avulsion to abruptly alter the channel of the Morse River away from the state park and a new bath house. Erosion reached much farther inland than ever recorded in the last century, but conditions are favorable for the beach and dunes to return naturally in the next several years.

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